THREE DIMENSIONAL PROJECTION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

The following patents and/or commonly assigned patent applications are hereby incorporated herein by reference:

Patent No.	Filing Date	Issue Date	Title
5,583,688	Dec. 21, 1993	Dec. 10, 1996	Multi-Level Digital Micromirror Device
09/705,467	Nov. 3, 2000		Sequential Color Recapture for Projection Systems
TI-28388	Nov. 30, 2000		Automated Convergence and Focus Verification of Projected Images

FIELD OF THE INVENTION

This invention relates to the field of display systems, more particularly to three dimensional display systems.

BACKGROUND OF THE INVENTION

Display systems create an image from electrical signals that represent the desired image. Many different criteria and performance metrics are used to evaluate the image quality, including brightness, contrast, resolution, color purity, and image uniformity. Modern display systems excel at all of these criteria and are capable of creating very high quality images.

One feature that is difficult for a display system to achieve is the perception of a three-dimensional image. Many methods have been devised to create a three-dimensional perception, including moving or rotating projection screens, shuttering the viewers eyes, and use of polarization. Unfortunately, these methods are not very practical to implement. Some of the

methods are too inefficient, others require too much alignment of multiple modulators in order to increase the brightness of the image to suitable levels.

What is needed is a system design that will allow projection of a three-dimensional image using a minimum number of modulators while utilizing as much of the source light available.

SUMMARY OF THE INVENTION

Objects and advantages will be obvious, and will in part appear hereinafter and will be accomplished by the present invention which provides a method and system for three dimensional image projection. One embodiment of the claimed invention provides a three dimensional image display system. The display system comprises: a light source, a sequential color filter, a polarizing beam splitter, a first and second spatial light modulator, and at least one projection lens. The light source provides a beam of light along an illumination path. The sequential color filter is on the illumination path and filters the light beam. The polarizing beam splitter is on the illumination path and separates the filtered light beam into a first beam having a first polarization state and a second beam having a second polarization state. The first spatial light modulator receives and selectively modulates the first beam. The second spatial light modulator receives and selectively modulates the second beam. The projection lens on a projection path focuses the first and second beams on an image plane.

One embodiment uses the polarizing beam splitter to recombine the modulated first and second light beams. Another alternate embodiment uses at least one prism in the illumination and projection paths to separating the filtered illumination light beam and the modulated light beam.

Another embodiment uses a first prism in the illumination and projection paths for separating the first beam directed to the first modulator and the modulated first beam from the first modulator; and a second prism in the illumination and the projection paths for separating the second beam directed to the second modulator and the modulated second beam from the second modulator.

Another embodiment positions the first and second modulators such that pixelated images from the first and second modulators are offset by approximately one-half pixel at the image plane.

Another embodiment of the disclosed invention provides a method of producing a three dimensional image. The method comprising: providing a beam of light along an illumination path; sequentially color filtering the light beam; splitting the filtered light beam into a first beam having a first polarization state and a second beam having a second polarization state; modulating the first beam using a first spatial light modulator; modulating the second beam using a second spatial light modulator; and focusing the first and second modulated light beams on an image plane.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a schematic view of a one embodiment of a three dimensional display system using two spatial light modulators and a single projection path.

FIGURE 2 is a schematic view of one embodiment of a three dimensional display system using two spatial light modulators and two projection paths.

FIGURE 3 is a perspective view of a recycling integrator and a spiral color wheel sequential color filter from Figures 1 and 2.

FIGURE 4 is a cross section side view of recycling integrator rod and sequential color filter of Figure 3 showing the light recycling function of the integrating rod.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A new three dimensional display system design and method has been developed that maximizes the efficiency of the system while limiting the number of modulators that are used to create the projected image.

While not necessary, the use of sequential color recapture, as described in U.S. Patent Application Serial No. 09/705,467 greatly improves the brightness of the display system by maximizing the usable light from the light source. The following description assumes the use of the recycling integrator rod and sequential color recapture, but it should be understood that other embodiments do not utilize sequential color recapture and the recycling integrator rod.

One embodiment of the three dimensional display system is shown in Figure 1, which is a schematic view of a three dimensional display system 100 using two spatial light modulators and a single projection path. In Figure 1, light source 102 emits a white light beam 104 which is focused onto a clear aperture of a recycling integrator 106. The light beam travels through the recycling integrator 106 and is reflected several times by the walls of the integrator 106. The multiple reflections homogenize the light beam giving it a uniform intensity across the width of the beam.

After leaving the exit end of the integrator, the homogenized light beam strikes a sequential color filter 108. The sequential color filter creates a filtered light beam. The filtered light beam comprises at least three spatially separated light beams. Each of the spatially separated light beams is comprised of a band of wavelengths giving the sub-beam a color. Typically three sub-beams are formed: a red, green, and blue sub-beam. Some embodiments include a fourth sub-beam comprised of white light.

A motor 110 spins the sequential color filter 108. The spinning makes the sub-beams move across the width of the combined beams. The portion of the sequential color filter 108 in the light path is imaged on the spatial light modulators 112, 114 such that each color sub-beam illuminates and is modulated by a subset of the modulator elements of the spatial light modulator. This sub-set changes as the sequential color filter rotates moving the sub-beams across the face of the modulator.

The filtered light beam, containing the colored filtered sub-beams, is separated by a polarizing beam splitter 116. The polarizing beam splitter 116 separates the light beam into two separate light beams, each comprising a portion of each color sub-beam created by the sequential color filter. A first portion of the light beam having a first polarization state is passed to a first spatial light modulator 112. A second portion of the light beam having a second polarization state is reflected to a second spatial light modulator 114.

The two modulators 112, 114 receive pixel data from a controller 118 and use the pixel data to modulate the light incident each of the modulators. The pixel data is derived from image data 120 representing the desired image and received by the controller 118. The first and second modulated light beams pass back through the polarizing beam splitter 116 and are combined into a single modulated light beam.

A projection lens 118 receives the modulated light beam and focuses the modulated light beam on an image plane 120. A viewer uses polarizing eyewear 122 to view the projected image. The polarizing eyewear 122 allows light of one polarization to pass through to the viewer's left eye, and light of the other polarization to pass through to the viewer's right eye. By providing proper pixel data to the modulators 112, 114, the perception of a three dimensional image is created.

The images produced by each of the spatial light modulators are focused on the image plane 120. Typically the images are converged such that the image created by a pixel of the first modulator overlies the image created by the same pixel of the second modulator. The pixel data provided to each of the pixels typically is offset to create the perception of the three dimensional image.

Alternatively, the images created by the two modulators are offset on the image plane. Offsetting the two images, typically by one-half of the spacing between the two pixels or less, may reduce the viewer's perception of the pixelization and create the perception of a higher resolution image. Additionally, when the images created by the two modulators is offset by one-half of the pixel pitch, an image with twice the resolution can be created for a viewer that does not wear the polarizing eyewear 122. Thus, a display with offset images can produce both three dimensional images an very high resolution two dimensional images. The offset may be in either the horizontal or vertical direction, or both.

Reflective spatial light modulators 112, 114 typically use an illumination beam 124 that strikes the modulator at an angle that is very close to normal to the surface of the modulator. The modulated light beam 126 leaves the modulator at an angle that is normal to the surface of the modulator or very close to the normal angle. Thus, there is very little separation between the incident illumination beam 124 and the reflected modulated beam 126 bearing the image. The lack of separation makes it difficult to place the projection lens 118 and the sequential color filter 108 in the projection and illumination light paths without interfering with each other.

One method of spatially separating the incident and reflected light beams is to use a prism. The prism separates the illumination and projection light beams by providing an interface that will cause one of the beams to reflect at the interface while allowing the other light beam to

pass through the interface. Figure 1 includes a TIR prism assembly comprised of two prisms which reflect the illumination beam 124 at the interface between the two prisms while allowing the projection light beam 126 to pass through the light beams.

A second embodiment of a three dimensional display system is shown in Figure 2, which is a schematic view of a three dimensional display system 200 using two spatial light modulators and a single projection path. In Figure 2, light source 102 emits a white light beam 104 which is focused onto a clear aperture of a recycling integrator 106. The light beam travels through the recycling integrator 106 and is reflected several times by the walls of the integrator 106. The multiple reflections homogenize the light beam giving it a uniform intensity across the width of the beam.

After leaving the exit end of the integrator, the homogenized light beam strikes a sequential color filter 108. The sequential color filter creates a filtered light beam. The filtered light beam comprises at least three spatially separated light beams. Each of the spatially separated light beams is comprised of a band of wavelengths giving the sub-beam a color. Typically three sub-beams are formed: a red, green, and blue sub-beam. Some embodiments include a fourth sub-beam comprised of white light.

As in Figure 1, a motor spins the sequential color filter 108 to make the sub-beams move across the width of the combined beams. The portion of the sequential color filter 108 in the light path is imaged on the spatial light modulators 112, 114 such that each color sub-beam illuminates and is modulated by a subset of the modulator elements of the spatial light modulator. This sub-set changes as the sequential color filter rotates moving the sub-beams across the face of the modulator.

The filtered light beam, containing the colored filtered sub-beams, is separated by a polarizing beam splitter 116. The polarizing beam splitter 116 separates the light beam into two separate light beams, each comprising a portion of each color sub-beam created by the sequential color filter. A first portion of the light beam 212 has a first polarization state and is passed to a first spatial light modulator 112. A second portion of the light beam 214 has a second polarization state and is reflected to a second spatial light modulator 114.

The two modulators 112, 114 receive pixel data from a controller 118 and use the pixel data to modulate the light incident each of the modulators. The pixel data is derived from image data 120 representing the desired image and received by the controller 118.

A projection lens 208 receives the modulated light beam from a first modulator 112 and focuses the modulated light beam onto the image plane 120. A separate projection lens 210 receives the modulated light beam from a second modulator 114 and also focuses the modulated light beam onto the image plane 120. Polarizing eyewear 122 separates the light from the image plane allowing the viewer to discern a 3D projected image. The polarizing eyewear 122 allows light of one polarization to pass through to the viewer's left eye, and light of the other polarization to pass through to the viewer's right eye. By providing proper pixel data to the modulators 112, 114, the perception of a three dimensional image is created.

It is difficult to align the various spatial light modulators such that the images produced by each of the spatial light modulators is properly converged. One of the potential advantages of the disclosed system is that only two modulators typically are used rather than the three or more used by other designs. Without the use of the scrolling color recycling integrator, the creation of a color image would require either a color splitting prism and three modulators, or the use of the color wheel and the sequential creation of single-color images. The three modulators are difficult

to converge and focus—given that two sets of three modulators would be necessary for a parallel color three dimensional display. Single modulator sequential color systems waste too much of the available light—since light of only one color is used at any given time—producing a dim image for a given lamp size.

Figure 3 is a perspective view of a recycling integrator and a spiral color wheel sequential color filter from Figures 1 and 2. In Figure 3, light enters an input aperture 302 of the integrating rod 304. The light travels the length of the integrating rod 304, reflecting from the sides of the integrating rod 304 as it travels along, until exiting from the opposite end of the integrating rod and striking a sequential color filter 306. The sequential color filter 306 shown in Figure 3 is a spiral color wheel. The spiral color wheel 306 shown in Figure 3 has color filter segments of three different colors. The three color filters include a first primary color filter 308, a second primary color filter 310, and a third primary color filter 312. The interfaces between these segments typically follow a spiral of Archimedes such that as the color wheel spins about its hub 314 the images of the interfaces projected on the device move in a somewhat linear fashion.

The three filter colors are all represented at the exit end of the integrating rod at all times so that light exiting the integrating rod includes sub-beams of each of the three primary colors. Figure 4 is a cross section side view of the integrating rod 402 and the sequential color filter 404 showing the recycling function of the integrating rod 402. In Figure 4, white light 406 enters the integrating rod 402 through an aperture 408 at the input end of the rod and travels through the integrating rod 402, reflected by the sides of the rod as it travels along.

The integrating rod 402 may be a solid rod made from a material that is transparent over the wavelengths of interest—for example, glass or acrylic. Alternatively, the integrating rod 402

may be a hollow structure. When the light strikes the sides of the integrating rod, it is reflected, either by a mirrored surface or by total internal reflection.

Upon exiting the exit end of the integrating rod 402, the light may strike any one of the filter elements positioned at the end of the integrating rod 402. The color filter 404 of Figure 4 includes four segments, one for each of the three primary colors: red, green, and blue, and one clear segment, often called a white segment, designed to pass all incident light.

White light 410 striking a red filter segment 412 is separated into a red light beam 414 which passes through the color filter and a cyan light beam 416 which is reflected. White light 410 striking a green filter segment 418 is separated into a green light beam 420 which passes through the color filter and a magenta light beam 422 which is reflected. White light 410 striking a blue filter segment 424 is separated into a blue light beam 426 which passes through the color filter and a yellow light beam 428 which is reflected. White light 410 striking the clear filter segment 430 passes through the filter segment.

Light rejected by the sequential color filter 404 in Figure 4 retraces its path through the integrator rod 402 to the entrance face of the rod. Most of the light 432 returning to the entrance face of the integrating rod is reflected by the reflective aperture—the reflective area around the input aperture—and returns to the exit face of the integrating rod 402. Ideally, the light returned to the exit face of the integrating rod strikes a different color filter allowing an additional component of the white light to exit the rod 402.

The use of the recycling integrating rod 402 of Figure 4 greatly improves the efficiency of a single modulator in a sequential color display system. As mentioned above, without the light recycling function, a given light source would produce a much dimmer projected image, or

would require additional modulators to produce a bright image. The additional modulators would required complex alignment and would drive up the cost of the display system.

Thus, although there has been disclosed to this point a particular embodiment for three dimensional projection system and method therefore, it is not intended that such specific references be considered as limitations upon the scope of this invention except insofar as set forth in the following claims. Furthermore, having described the invention in connection with certain specific embodiments thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art, it is intended to cover all such modifications as fall within the scope of the appended claims. In the following claims, only elements denoted by the words “means for” are intended to be interpreted as means plus function claims under 35 U.S.C. § 112, paragraph six.